Anatomical and Chemical Properties of Keruing Wood from Labanan Research Forest, East Kalimantan

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Abstract

Understanding the basic properties of wood is essential for its appropriate and efficient utilization. Anatomical feature for many species of wood, as an important basic property of wood, remained incomplete and mostly limited to the genus level, especially for Dipterocarpaceae. In the present works, three keruing species i.e. (*Dipterocarpus stellatus* Vesque, *Dipterocarpus glabrigemmatus* P.S. Ashton, and *Dipterocarpus pachyphyllus* Meijer) were studied for their anatomical and chemical properties. Observation of the microscopic and macroscopic features of these woods was conducted. Suitability of the wood for pulp and paper raw material was also assessed through fiber dimension measurement. Chemical component analyses were carried out based on appropriate Technical Association of the Pulp and Paper Industries (TAPPI) standard procedures. The result showed that in general, all species have resemblance in both anatomical and chemical properties. Even though, the lignin and extractives content of the three *Dipterocarpus* spp. were considered high, their fiber were classified as class I fiber quality; and thus very suitable for the raw material of pulp and paper production.

Keywords: anatomical properties, chemical properties, *Dipterocarpus* spp., fibre quality, keruing

Abstrak

Sifat anatomi dan kimia kayu merupakan sifat dasar kayu yang penting untuk menentukan potensi kegunaan kayu secara tepat. Informasi ciri anatomi jenis kayu juga diperlukan untuk melengkapi database identifikasi kayu yang hingga saat ini masih terbatas pada tingkat marga, khususnya jenis kayu dari suku Dipterocarpaceae yang variasi jenisnya sangat banyak dalam setiap marganya. Dalam penelitian ini tiga jenis kayu keruing (*Dipterocarpus stellatus* Vesque, *Dipterocarpus glabrigemmatus* P.S. Ashton, and *Dipterocarpus pachyphyllus* Meijer) dipilih untuk diketahui ciri anatomi dan kimianya. Pengamatan ciri anatomi dilakukan baik seara makroskopis maupun mikroskopis. Sedangkan pengujian kimia dilakukan berdasarkan standard Technical Association of the Pulp and Paper Industries (TAPPI). Hasil penelitian menunjukkan bahwa ketiga jenis keruing yang diteliti memiliki kemiripan baik secara anatomi maupun kimia. Berdasarkan kriteria penilaian kualitas serat, ketiga jenis masuk ke dalam kelas kualitas I yang berarti baik digunakan sebagai bahan baku pulp dan kertas. Namun, ketiga jenis tersebut memiliki kandungan zat ekstraktif yang tinggi. Oleh Karena iu, apabila kayu tersebut akan digunakan untuk pembuatan pulp dan kertas maka diperlukan perlakuan awal untuk mengurangi kandungan lignin dan zat ekstraktif yang tinggi.

Kata kunci: *Dipterocarpus spp.*, keruing, kualitas serat, sifat anatomi, sifat kimia

Introduction

Keruing (*Dipterocarpus* spp.) is one of groups from Dipterocarpaceae family which has high potential as a producer of timber and non-timber forest products. According to Boer and Ella (2001), *Dipterocarpus* spp. consists of 69 species and 20 species of them can produce oil. Keruing oil used to make varnish, medicine, and aromatic materials. Indonesia has 38 species of Dipterocarpus that mostly grown in primary forests of Kalimantan and Sumatra (Kartawinata 1983).

The utilization of *Dipterocarpus* spp. to date mostly focused on timber forest products to meet the demand for wood working industry. Exploitation activities usually carried out only by its trade name without considering the species level. Therefore, the existence of species in the wild more decrease and become threatened. According to IUCN (2012), as many 26 species of Dipterocarpus have listed into IUCN Red List for Threatened Species in the category of vulnerable (1 species), endangered (1 species), critically endangered (23 species) and extinct (1 species). However, there are still many species have not been observed especially for their anatomical and chemical properties of wood.

Wood anatomical features are indispensable in wood identification activities which beneficial for various purposes such as combating illegal trade of wood products, identifying archaeological wood products and identifying the botanical identity of silicified wood. Each wood species has characteristics as a key differentiator for wood identification purposes. The database for wood identification should be continuously updated until species level. Generally, wood identification can only be undertaken up to the level of genus including Dipterocarpacae family that has the largest members. Therefore, research on wood anatomy is needed to determine the characteristics of each species from Dipterocarpaceae family for completing the wood identification database.

Anatomical properties also can be used to predict the quality of wood especially from its cell dimension. The estimation can be comprehensively supported by the chemical properties of wood. Both properties can be linked together to determine the potential utilization of wood. This research focus on investigating the anatomical properties and chemical component of three *Dipterocarpus* spp. This study is needed to provide information on its possible uses of selected wood based on anatomical properties and chemical component.

Materials and Methods

Three Keruing wood samples i.e. *Dipterocarpus stellatus, Dipterocarpus glabrigemmatus* and *Dipterocarpus pachyphyllus* were selected from Labanan Research Forest, Berau, East Kalimantan. The criteria of the samples were tree with straight stem, more than 40 cm in diameter, and free of defects. The trees were felled at the bottom part or 20 cm above buttress using a chain saw. After the tree felled down, disk samples with 10 cm thickness were taken from bottom, middle, and top part of the stem.

Anatomical characteristics observation

Macroscopic and microscopic anatomical characteristics were observed. The observed macroscopic or general characteristics of wood surface included colour, figure, texture, grain orientation, lustreness, touchness, hardness and odour (Mandang & Pandit 2002). For microscopic observation, wood sample with the size of (1.5x1.5x1.5) cm^3 was taken from the middle part (between pith and bark) of the bottom disk. The microscopic slides were prepared by following Sass (1961) method. Wood samples were prepared and soaked with distilled water for one night, and then submerged into 50:50 alcohol and glycerine for 2-3 days. Then, the samples sliced with a microtome to obtain 15-25 μ thick covering cross, radial and tangential section. The best slices were washed with distilled water to remove glycerine, and then the slices were stained with safranin, dehydrated with series of alcohol concentration (30%, 50%, 70%, and 96%), and cleaned with xylene and toluene. Then, the material was mounted on a glass slide with enthellan and observed under a light microscope for anatomical features listed by IAWA (Wheeler *et al.* 1989).

Samples for fibre dimensions, their derivative values, and other microscopic characteristics of individual fibers were taken from disk of the bottom part of the trees. Three wood samples of (1.5x1.5x1.5) cm^3 in size were taken from pith to bark of the bottom disk. The samples were cut into wood chips, then macerated according to Forest Product Laboratory method (Tesoro 1989) that using a mixture of equal parts of 60% glacial acetic acid and hydrogen peroxide (20% by volume), heated at 80 ºC for 1-2 days or until the sample is colourless and soft. Macerated samples were washed with tap water until acid free. The separated fibers were stained with safranin for 3 hours, then washed with distilled water and placed on a glass slide using a pippete. Afterwards, several drops of glycerine were dropped down gently on to the separated fibers. Then, it was covered with a cover glass for further observation on those individual fibers under a light microscope. The observation comprised the measurement of individual fiber dimensions i.e. fibre length (n = 25), fibre diameter (n = 15) and lumen diameter (n = 25). Afterwards, the derived values of fiber dimension were calculated using the following formulas:

$$RR = \frac{2w}{l} \qquad CR = \frac{w}{d}$$

$$FP = \frac{L}{d} \qquad FR = \frac{l}{d}$$

$$MR = \frac{(d^2 - l^2)}{d^2} \times 100\,\%$$

where RR = Runkel ratio

l = Lumen diameter

FP = Felting power

L = Fiber length

MR =Muhlsteph ratio

d = Fiber diameter

FR = Flexibility ratio

w = Wall thickness

CR = Coefficient of rigidity (obtained by subtraction: (d-l)/2)

The fiber quality was classified based on the criteria shown in Table 1.

Table 1 Fiber quality criteria for pulp and paper raw material

Criteria	Class I		Class II		Class III	
	Requirement	Score	Requirement	Score	Requirement	Score
Fiber length, µm	> 2000	100	1000-2000	50	< 1000	25
Runkel ratio (RR)	< 0.25	100	0.25-0.50	50	0.50-1.0	25
Felting power (FP)	> 90	100	50-90	50	< 50	25
Muhlsteph ratio (MR)	< 30	100	30-60	50	60-80	25
Flexibility ratio (FR)	> 0.80	100	0.50-0.80	50	< 0.50	25
Coefficient of rigidity (CR)	< 0.10	100	0.10-0.15	50	> 0.15	25
Interval	450-600		225-449		< 225	

Source: Rachman and Siagian (1976)

Chemical properties observation

Wood samples for chemical testing were selected from each part of the stem (bottom, middle, and top) which cut into small pieces of wood (chips). Chips were naturally dried to 12-15% moisture content. The next process is making wood powder of 60-mesh size using a hammer mill . Then, the air-dried powder is stored in a sealed plastic bag to prevent moisture content change. The content of holocellulose, cellulose, hemicellulose, lignin, and extractives (soluble cold water, hot water, 1% NaOH, alcohol, benzene, and ash content) were then determined following the standard procedures of TAPPI standard (TAPPI 1989).

Results and Discussion

Anatomical properties

Dipterocarpus stellatus **Vesque**

General characteristics: heartwood is reddish brown, distinctly demarcated from the light brown sapwood, somewhat coarse texture, grain straight sometimes combined, touch impression rough, wood hard, and there are liquids such as oil on wood.

Anatomical properties: Growth ring is indistinct. Vessels: diffuse, exclusively solitary with rounded shape, mean diameter of vessel lumina is 101.6 µm, 858 µm in length, 5 mm^{-2} in frequency. Perforation plate is simple. Intervessel pits alternate and opposite, pits vestured. Vessel-ray pits with much reduced border to apparently simple, pits horizontal and angular. Tyloses common in vessels. Vasicentric tracheids present. Axial parenchyma: apotracheal diffuse-in-aggregates, paratracheal vasicentric, lozenge-aliform, and 4-6 cells per parenchyma strand. Rays: uniseriate and multiseriate (3-5). Cellular compositions are procumbent body ray cells with 3-5 rows of upright cells. Fiber: 2167 µm in length, non septate, and very thick-walled with simple to minutely bordered pits. Intercellular canals: short tangential line and diffuse. Silica: present. Anatomical structure of *D. stellatus* is presented in Figure 1.

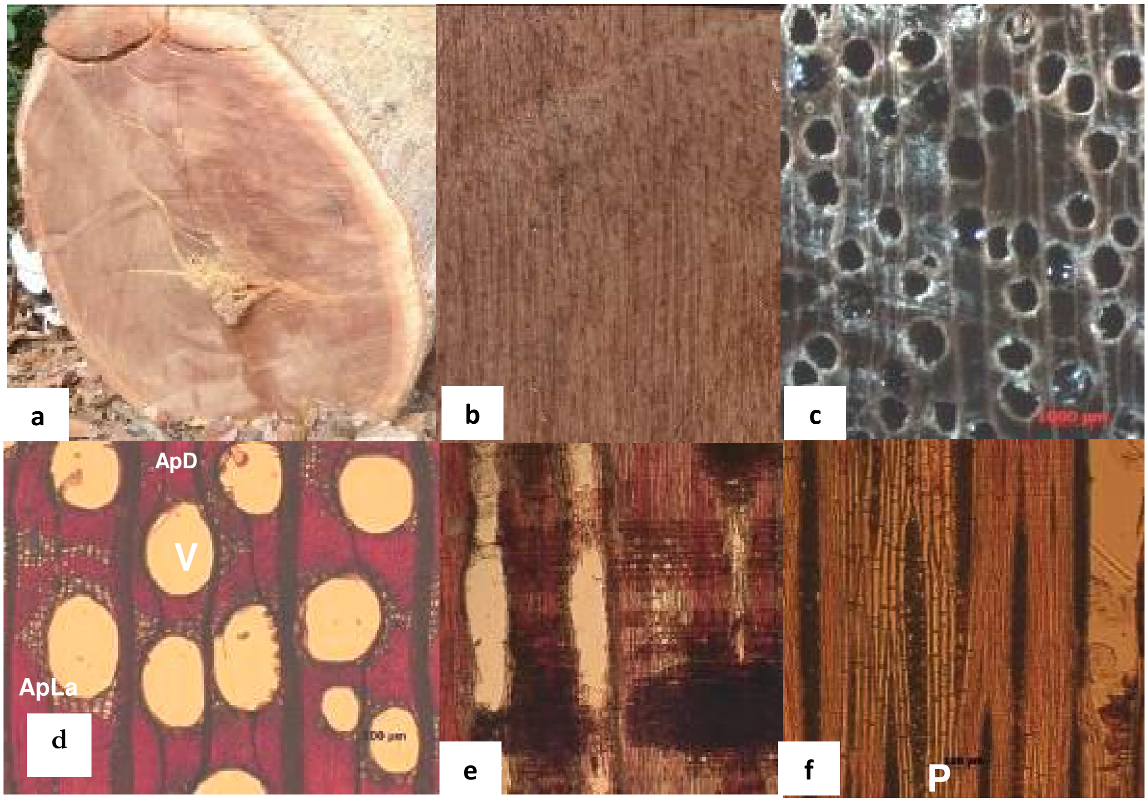

Figure 1 *D. stellatus* (a) Cross sectional surface of the stem (b) longitudinal surface (c) transverse surface (macroscopic) d) transverse surface (microscopic) (e) radial surface (f) tangential surface; V: vessel, ApD: apotracheal parenchyma diffuse in aggregate, ApLa: apotracheal parenchyma lozenge-aliform, P: parenchyma.

***D. glabrigemmatus* PS Ashton**

General characteristics: heartwood is reddish brown, distinctly demarcated from the light reddish brown sapwood, somewhat coarse texture, grain straight sometimes combined, touch impression rough, wood hard, and there are liquids such as oil on wood.

Anatomical properties: Growth ring is indistinct. Vessels: diffuse, exclusively solitary with rounded shape, mean diameter of vessel lumina is 108.9 µm, 674 µm in length, 4 mm^{-2}. Perforation plate is simple. Intervessel pits alternate and opposite, pits vestured. Vessel-ray pits with much reduced border to apparently simple, pits rounded. Tyloses is common in vessels. Vasicentric tracheids present. Axial parenchyma: unilateral paratracheal and 3-9 cells per parenchyma strand. Rays: uniseriate and multiseriate (2-4). Cellular compositions are procumbent body ray cells with 1-3 rows of upright cells. Fiber: 1984 µm in length, septate, and very thick-walled with simple to minutely bordered pits. Intercellular canals: short tangential line. Silica: present. Anatomical structure of *D. glabrigemmatus* is presented in Figure 2.

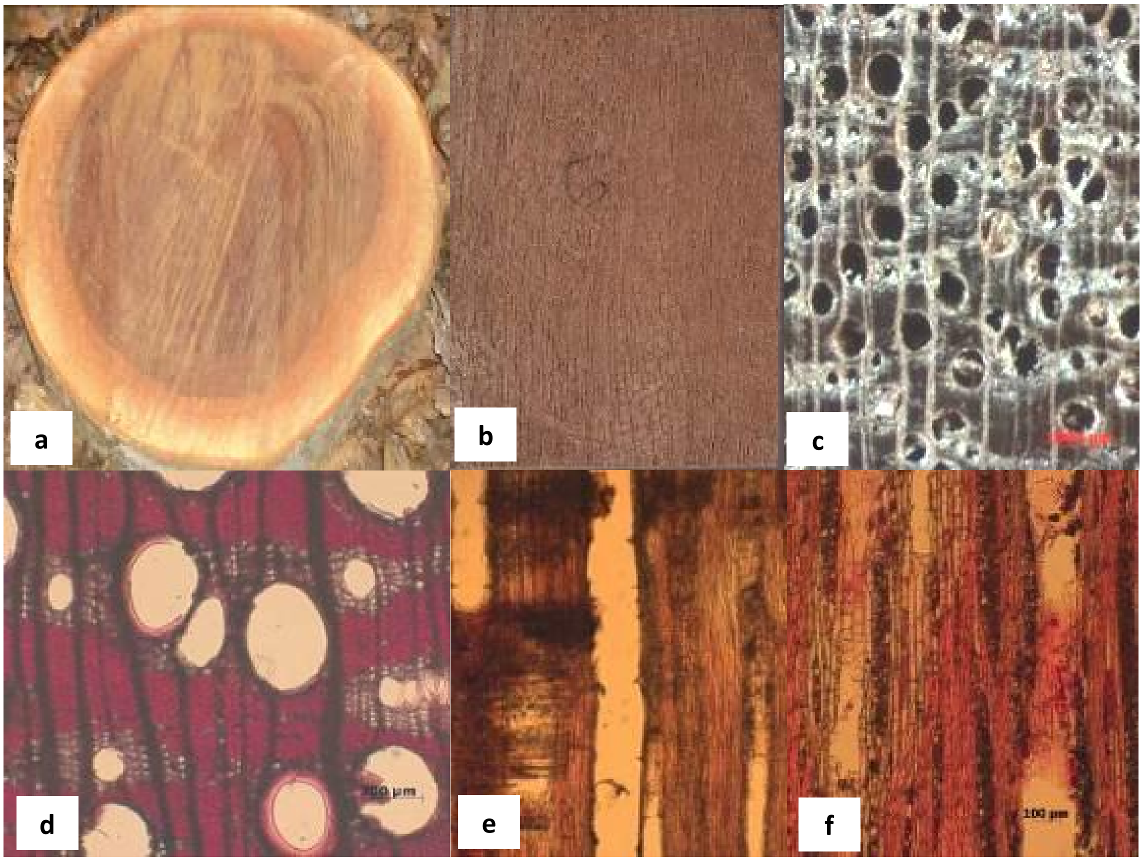

Figure 2 *D. glabrigemmatus* (a) Cross sectional surface of the stem (b) longitudinal surface (c) transverse surface (macroscopic) d) transverse surface (microscopic) (e) radial surface (f) tangential surface.

D. pachyphyllus **Meijer**

General characteristics: reddish brown heartwood, distinctly demarcated from light brown sapwood, somewhat coarse texture, grain straight sometimes combined, touch impression rough, wood hard, and there are liquids such as oil on wood.

Anatomical properties: Growth ring is indistinct. Vessels: diffuse, exclusively solitary with rounded shape, mean diameter of vessel lumina is 194.1 µm, 716.19 µm in length, 6 mm^{-2}. Perforation plate is simple. Intervessel pits scalariform, pits vestured. Vessel-ray pits with distinct border; similar to intervessel pits in size and shape. Tyloses is common in vessels. Vasicentric tracheids present. Axial parenchyma: unilateral paratracheal and 3-6 cells per parenchyma strand. Rays: uniseriate and multiseriate (2-4). Cellular compositions are procumbent body ray cells with 2-4 rows of upright cells. Fiber: 1946 µm in length, septate and non septate, and very thick-walled with simple to minutely bordered pits. Intercellular canals: short tangential line. Silica: present. Anatomical structure of *D. pachyphyllus* is presented in Figure 3.

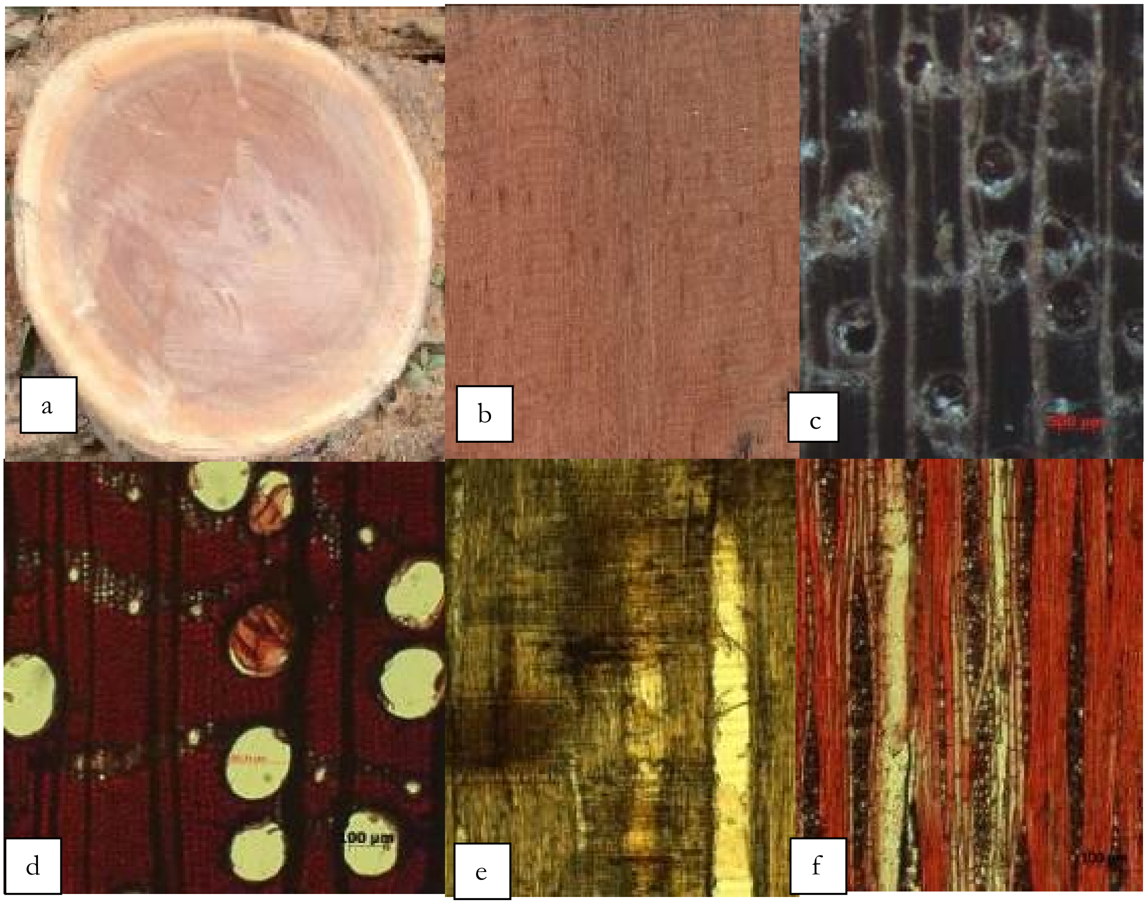

Figure 3 *D. pachyphyllus* (a) Cross sectional surface of the stem (b) longitudinal surface (c) transverse surface (macroscopic) d) transverse surface (microscopic) (e) radial surface (f) tangential surface.

In general, three *Dipterocarpus* spp. have similar anatomical features. They have in common in indistinct growth rings boundaries, vessel mostly solitary with rounded shape, vessels diffuse, simple perforation plate, tyloses present, heterogeneous rays, vasicentric tracheids present, ground tissue fiber with simple to minutely bordered pits, very thick-walled fiber, two distinct sizes of rays, and the presence of silica. The similarities among three selected Dipterocarpus were also found in the previous study by Damayanti and Malik (2009) who studied *D. humeratus* v. Slooten and *D. hasseltii* Blume. A study by Fei-Tan (1974) also mentioned that vasicentric tracheids always present in all Dipterocarps, the cells irregular in shape and with conspicuous bordered pit. In hardwood, the function of vasicentric tracheids is providing mechanical power which is always associated with vessels (Pandit & Kurniawan 2008). Soerianegara and Lemmens (1994) stated that very thick wall fiber in *Dipterocarpus* spp. influence the heaviness and high shrinkage of wood.

The differences of anatomical features were found in intervessel pits, vessel-ray pits, septate fiber, parenchyma, ray-width, ray cellular composition, and intercellular canal. Details of the differences shown in Table 2.

Table 2 The Differences of anatomical properties of three *Dipterocarpus* spp.

Anatomical features	*D. stellatus*	*D. glabrigemmatus*	*D. pachyphyllus*
Intervessel pits	Opposite and alternate**	Opposite and alternate**	Scalariform*
Vessel-ray pits	Vessel-ray pits with much reduced border to apparently simple, pits horizontal and angular*	Vessel-ray pits with much reduced border to apparently simple, pits rounded*	Vessel-ray pits with distinct border; similar to intervessel pits in size and shape*
Septate fibers	Nonseptate fibers present*	Septate fibers present*	Septate and nonseptate fiber present*
Parenchyma	Apotracheal axial parenchyma diffuse-in-aggregates (ApD) - paratracheal axial parenchyma vasicentric and lozenge-aliform (ApLa)*	Axial parenchyma unilateral paratracheal**	Axial parenchyma unilateral paratracheal**
Axial parenchyma cell type/strand length	4-6 cells per parenchyma strand*	3-9 cells per parenchyma strand*	3-6 cells per parenchyma strand*
Ray width	Uniseriate and Multiseriate (3-5)*	Uniseriate and Multiseriate (2-4)**	Uniseriate and Multiseriate (2-4)**
Ray cellular composition	Body ray cells procumbent with 3-5 rows of upright cells*	Body ray cells procumbent with 1-3 rows of upright cells*	Body ray cells procumbent with 2-4 rows of upright cells*
Intercellular canals	Axial canals in short tangential line and diffuse*	Axial canals in short tangential line**	Axial canals in short tangential line**

Remarks: *: different characteristics **: the same characteristics

Quantitative features measured in this study are vessels, rays, fiber dimension, and cell percentage. Quantitative features are also required as the distinguishing feature of the wood identification. Detail of quantitative features shown in Table 3.

According to the IAWA (Wheeler *et al*. 1989), the average vessel diameter of *D. stellatus*, *D. glabrigemmatus*, *D. pachyphyllus*) are very large (> 200 m). For the vessel length of *D. stellatus* (858 m) included into high category, other species were moderate.

Table 3 Quantitative features of *Dipterocarpus* spp.

Anatomical features	Species		
	D. stellatus	*D. glabrigemmatus*	*D. pachyphyllus*
Vessel			
- Diameter, µm	376	311	254
- Mean vessel length, µm	858	674	716
- Vessel per mm^2	4	4	6
Rays			
- Rays height, µm	1645	1103	1025
- Rays width, µm	57	51	44
- Rays per mm^2	5	5	6
Fiber, µm			
- Fiber length	2167	1984	1946
- Fiber diameter	37	36	33
- Lumen diameter	32	31	29
- Wall-thickness	3	3	2
Cell percentage, %			
- Vessel	22	19	14
- Rays	27	23	25
- Parenchyma	4	9	4
- Fiber	47	46	56
- Axial intercellular canal	-	3	1

Vessel frequency of *D. stellatus* and *D. glabrigemmatus* included into very rare, whereas *D. pachyphyllus* included into rare. Rays height of *D. stellatus* (1.645 m) is high, other species in medium category. Rays width of *D. stellatus* and *D. glabrigemmatus* rather wide category, while *D. pachyphyllus* included into somewhat narrow. Rays frequency of three species classified as moderate category.

Based on IAWA Classification (Wheeler *et al*. 1989), fiber length of the three species is classified as long fiber. The fiber diameter included into large category (Casey 1960). According to Wagenfeur (1984), the category of lumen diameter of three species included into very large with very thin wall fiber.

The fiber dimension and its derived values are used to determine fiber quality as pulp and paper raw material. Detail of fiber quality values shown in Table 4.

Fiber length affects the physical properties of paper such as strength and stiffness. Long fibers allow wider bonds between fibers but the paper will be rough.

Table 4 Fiber quality values of *Dipterocarpus* spp

Criteria		Species		
		D. stellatus	*D. glabrigemmatus*	*D. pachyphyllus*
Fiber length, μm	Mean	2167.00	1984.00	1946.00
	Score	100.00	50.00	50.00
Runkel ratio	Mean	0.17	0.17	0.17
	Score	100.00	100.00	100.00
Felting power	Mean	58.51	55.60	58.37
	Score	50.00	50.00	50.00
Muhlsteph ratio, %	Mean	27.45	26.94	26.35
	Score	100.00	100.00	100.00
Flexibility ratio	Mean	0.85	0.85	0.86
	Score	100.00	100.00	100.00
Coefficient of rigidity	Mean	0.07	0.07	0.07
	Score	100.00	100.00	100.00
Total score		550.00	500.00	500.00
Quality class		I	I	I

Note: scoring standard base on Rahman and Siagian (1976)

The longer wood fiber will produce paper that has better strength properties because it has wider inter-fiber bonding area and better stress transfer at the time of milling process. Sheet strength properties that influenced by fiber length are tensile strength, folding resistance, and particularly tear resistance. On the other hand, the shorter wood fibers capable of producing smoother and uniform paper sheet (Casey 1980). According to the fiber quality criteria by Rachman and Siagian (1976), fiber length value and Runkel ratio value of three *Dipterocarpus* spp. belonged to quality class I.

Felting power affect tear strength of paper. The higher value of felting power, the fibers tend to be more flexible (Tamolang & Wangaard, 1961 in Sofyan *et al.* 1993). Based on the fiber quality criteria by Rachman and Siagian (1976), felting power value of three *Dipterocarpus* spp. belonged to quality class II. Wood fibers with a high Muhlsteph ratio have smaller surface area, therefore the bonding area and contact between the fiber decreases. This causes the resulting sheet of paper tend to have low tensile strength and crack resistance.

According to the fiber quality criteria by Rachman and Siagian (1976), Muhlsteph ratio value of *Dipterocarpus* spp. Belonged to quality class I. Flexibility ratio has a role in the development of fiber-to-fiber contacts. Fibers with high flexibility ratio causes the resulting sheet of paper has good strength, low porosity, and high density (Casey 1980). Fibers with high coefficient of rigidity show that the fiber has a higher density. Panshin & Zeeuw (1980) said that high fiber density has a good relationship with pulp yield. In addition, the resulting fiber will also produce a sheet of paper with high opacity, more rugged, larger dimensions, and high tear strength. Based on the fiber quality criteria by Rachman and Siagian (1976), flexibility ratio and coefficient of rigidity value of *Dipterocarpus* spp. belonged to quality class I.

According to all analysed parameters (fiber length, Runkel ratio, felting power, Muhlsteph ratio, flexibility ratio, and coefficient of rigidity), all *Dipterocarpus* spp. belonged to quality class I. Fiber with quality class I have good tear resistance, crack resistance and tensile strength. It is because the fibers are easy to be flattened in pulp sheet making (Rachman and Siagian, 1976). Therefore, these species are suitable for pulp and paper raw material.

Chemical properties

The chemical properties of wood in this investigation consist of the percentage of extractive substances, ash content, lignin content, and holocellulose content. The testing results of chemical properties of three species are presented in Table 5.

All three species have high extractive content (> 4 %). If the tree species will be used as raw materials for paper, veneer, or plywood, pretreatment is required to reduce high content of extractive substances. Generally, the solubility of extractive substances used as a reference in the utilization of wood is solubility in alcohol benzene. This mainly related to the types of compounds dissolved in many solvents, such as tannins, essential oils, fats and resins that are insoluble in other solvents.

Scharai-Rad (1983) said that the elements of inorganic (mineral elements) in wood are different for various kinds, ranging up to 4% for tropical timber. According to Directorate General of Forestry (1976), ash content of all species belonged to medium category (0.2-6%) which can be used as fuel or energy producers.

Lignin is one of the second largest substances in the wood with percentage from 17-32% by weight of water-free. Lignin spread across the entire wood either based on the location of altitude or cross section (Casey 1980). Based on DGF (1976), the lignin content of keruing wood (*D. pachyphyllus, D. glabrigemmatus and D. stellatus*) including high-class. According to Casey (1980), the holocellulose content for hardwood is 70-82%. The high content of holocellulose shows that the cellulose content in the wood is also high.

High levels of cellulose can be used to estimates the yield of pulp and paper. Through proper processing, the wood that has high cellulose content can produce pulp with high yield.

Table 5 Chemical composition of *Dipterocarpus* spp.

Species	Extractive substance, %				Ash content, %	Lignin content, %	Holo-cellulose content, %
	Soluble cold water	Soluble hot water	Soluble 1% NaOH	Soluble alcohol-benzene			
D. glabrigemmatus	12.2	14.3	23.8	8.8	0.5	33.4	72.7
D. pachyphyllus	16.0	16.8	27.9	7.7	0.1	34.2	76.9
D. stellatus	8.0	10.2	22.2	6.8	0.7	35.0	72.9

Conclusions

D. stellatus, D. glabrigemmatus, and *D. pachyphyllus* generally have the same general characteristics such as reddish brown heartwood, distinctly demarcated from sapwood, somewhat coarse texture, grain straight sometimes combined, touch impression rough, wood hard, and there are liquids such as oil on wood. The main microscopic characters of three species are indistinct growth rings boundaries, vessel mostly solitary with rounded shape, vessels diffuse, simple perforation plate, tyloses present, heterogenous rays, vasicentric tracheids present, ground tissue fiber with simple to minutely bordered pits, very thick-walled fiber, and two distinct sizes of rays. According to all parameters analysed (fiber length, Runkel ratio, felting power, Muhlsteph ratio, flexibility ratio, and coefficient of rigidity), all species included into quality class I. Fiber with quality class I have good tear resistance, crack resistance, and tensile strength. Therefore, these species are suitable for pulp and paper raw material which also supported by high content of holocellulose. On the other hand, the three species has a high extractive content. If all species will be used as a raw material for pulp and paper, pre-treatments are required to reduce the high content of lignin and extractive substance.

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